ECE-595 Network Softwarization

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The Need for Satellite Communication Networks

Today, still a large number of persons living in remote areas or in underdeveloped regions do not have a realistic perspective of achieving a broadband access to the Internet for many years.

- Such **digital divide problem** can be solved by satellite communications that can easily reach the different regions on the earth by providing everywhere the same service types.

Satellite communication systems also represent an adequate solution for the **rapid deployment of innovative and high bit-rate services** to users over wide areas.

Due to their nature, when interconnected together with local or geographical networks, **satellites can be the bottleneck of the entire system**, because of the delay and throughput that they entail.

- Obtaining the maximum performance out of the satellite segment is very important for achieving a reasonable cost of the service.

Satellite Communications

Winning aspects of satellite communications:

- Wide coverage area
- Rapid deployment of new services in broad areas and developing countries
- Easy fruition of both broadcast and multicast high bit-rate multimedia services
- Integration with terrestrial fixed and wireless networks for a joint service provision and traffic offloading schemes
- Internet access for people on flights, trains, and ships
- Support of emergency and backup services in the presence of environmental emergencies and traffic peaks.

Satellite Communications: Challenges

Dynamically-varying channel characteristics (atmospheric events, fading, shadowing, blockage, etc.)

- The lack of channel reliability requires the adoption of countermeasures such as: link margins, adaptive modulation and coding, diversity schemes, retransmissions, network coding, etc.

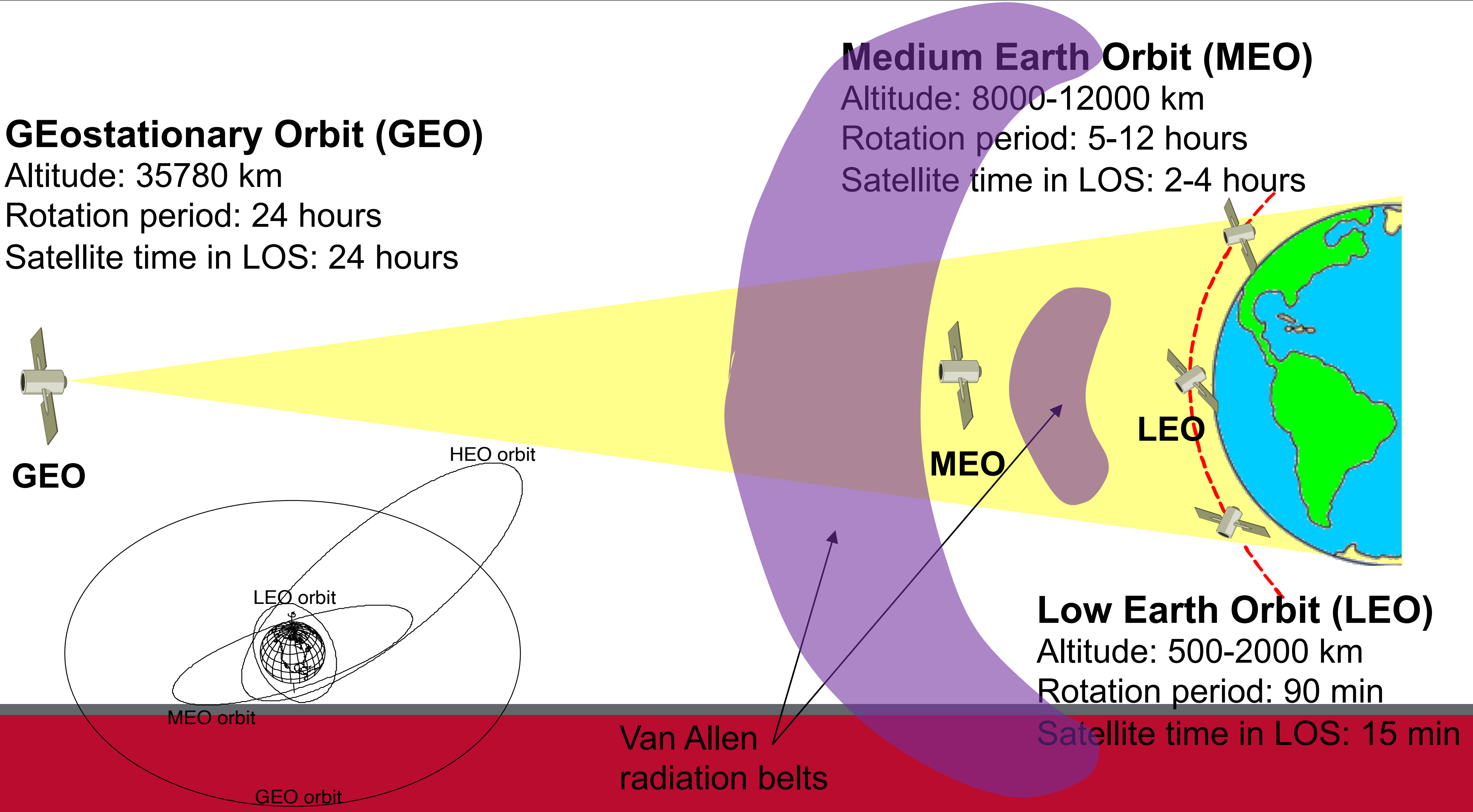
Bandwidth shortage and high cost of use: there is the need of using the available bandwidth in the most efficient way to support broadband applications.

Limited capabilities (antenna size, available power) in case of portable terminals.

Satellite Communications Frequency Bands

Letter designation for satellite frequency band	Frequency Range, GHz
L	1-2
S	2-4
C	4-8
X	8-12 (8-12.5 in North America)
Ku	12-18 (12.5-18 in North America)
Ka	27-40

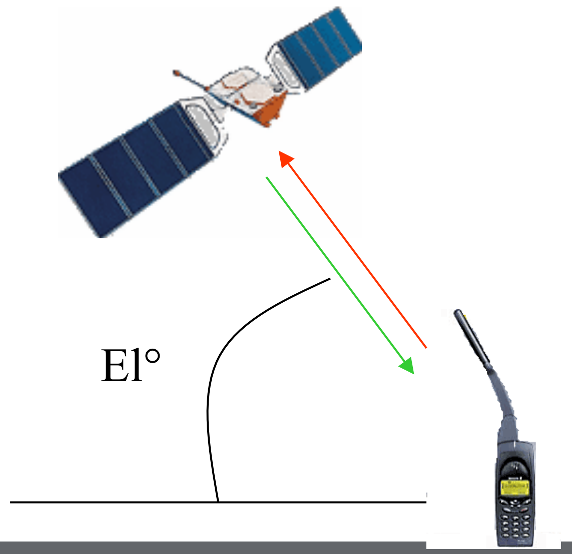
Satellite Orbit Types: GEO, MEO, LEO, and HEO



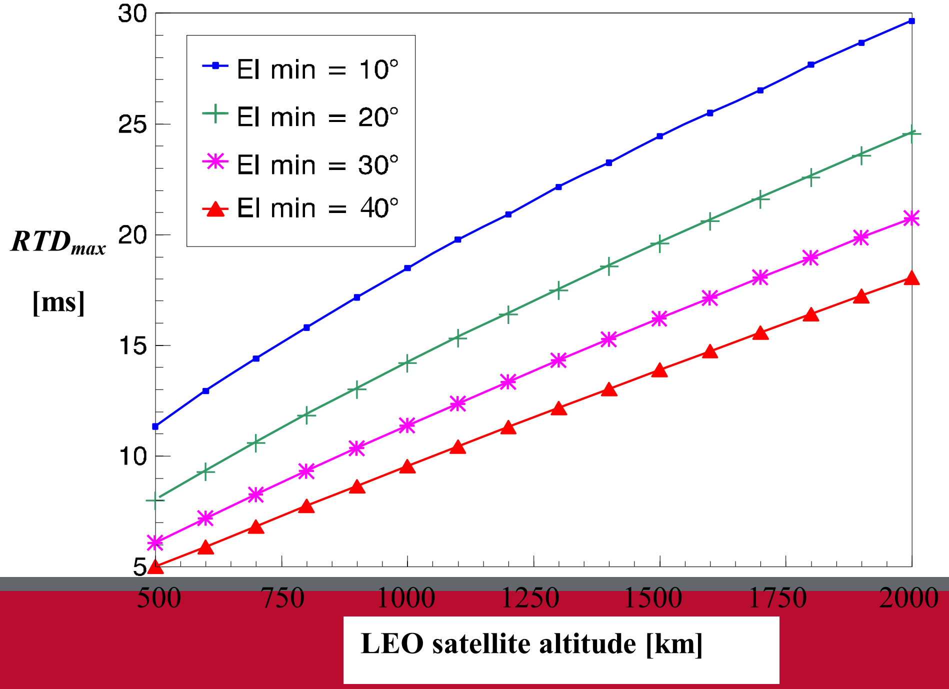
Round Trip propagation Delay (RTD)

RTD depends on the satellite altitude and the minimum Elevation angle El (**mask angle**). For bent-pipe (transparent) satellites, RTD refers to the communication from the user terminal to the terrestrial gateway via the satellite and back.

High RTD values prevent an immediate feedback to users (impact on MAC performance). In TDMA-based air interfaces, the super-frame duration should be greater than or equal to RTD since resource allocations cannot be updated more frequently.

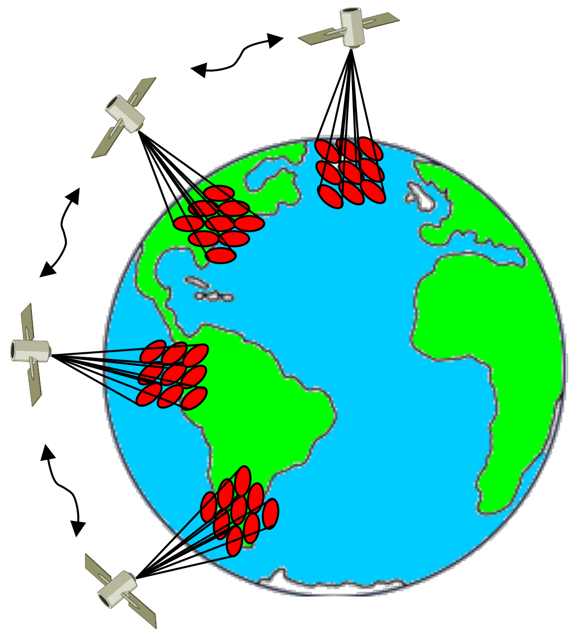


Case with regenerating satellite



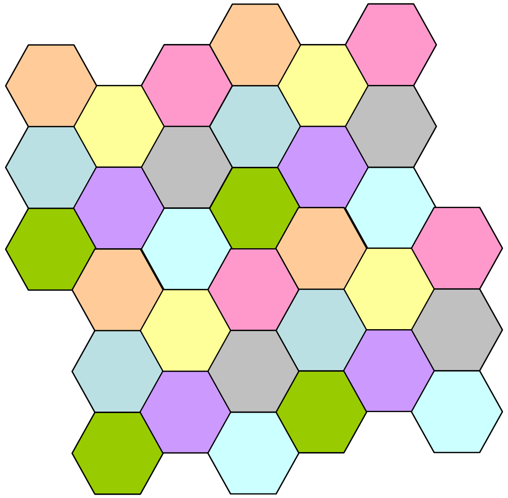
Satellites with Multi-Spot-Beam Antennas

The coverage area of a satellite is divided into many **cells** (each irradiated by an antenna **spot-beam**) in order to concentrate the energy on a small area. Thus, it is also possible to shape the served area on the earth.

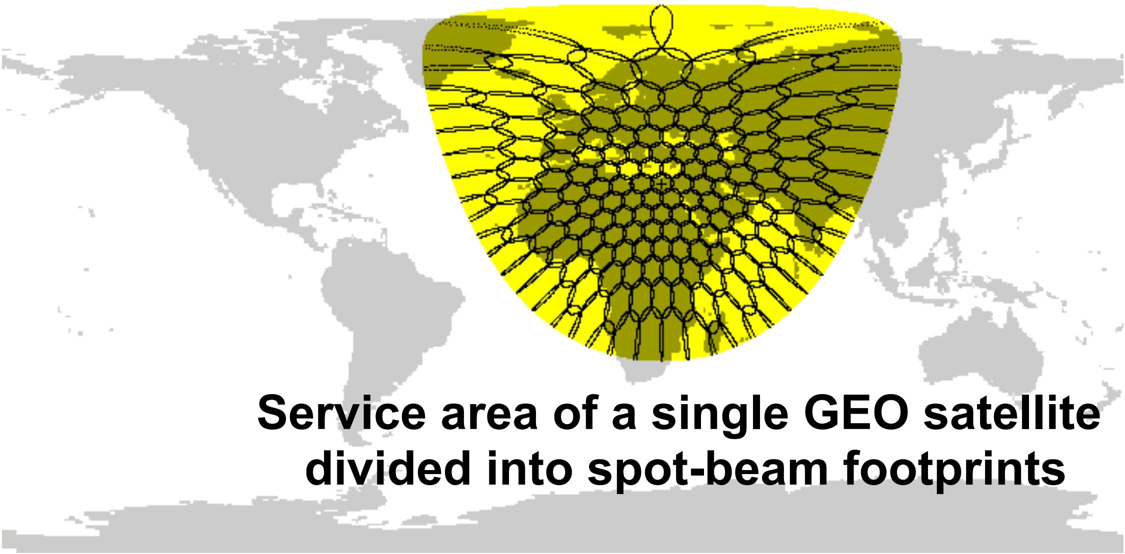


Frequency Reuse among Antenna Beams

The adoption of a multi-spot-beam antenna on the satellite allows us **to reuse the same frequency bandwidth many times in sufficiently-separated beams** to avoid interference. This approach permits to increase the traffic load supported by a satellite.

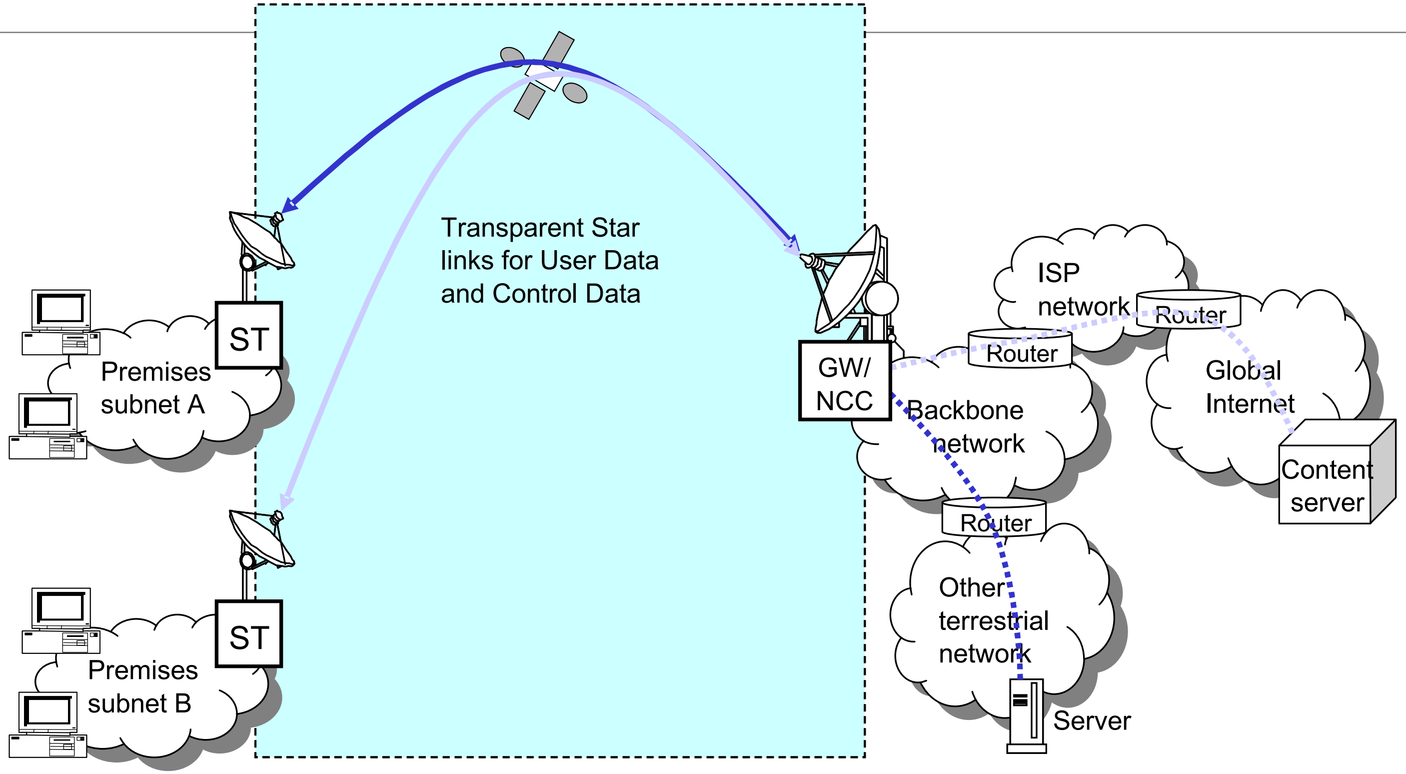


Frequency reuse pattern with 7 colors



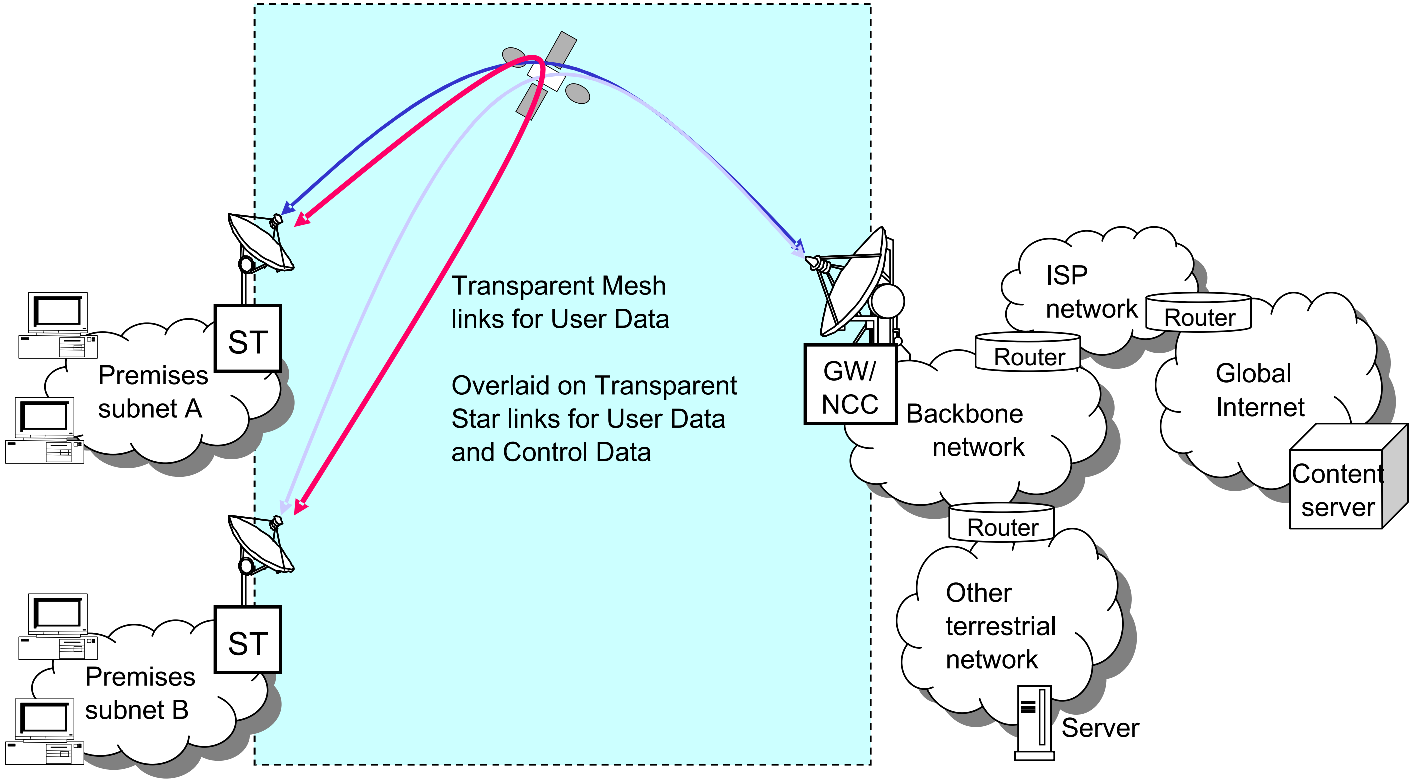
Service area of a single GEO satellite divided into spot-beam footprints

Transparent Satellite Star Architecture



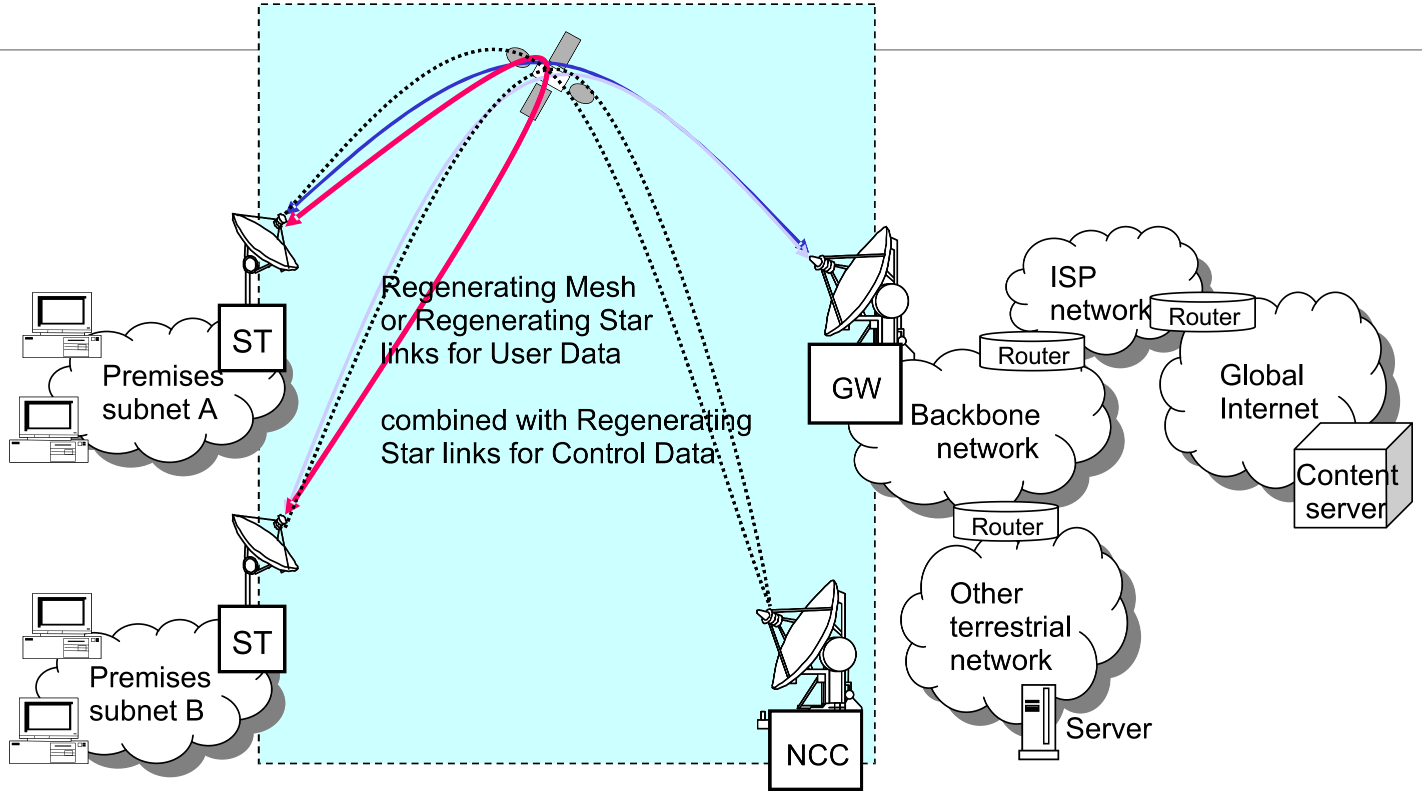
Satellite Terminal (ST)-to-ST communications require two hops via the terrestrial gateway. The satellite is bent-pipe.

Transparent Satellite Mesh Architecture



ST-to-ST communications require one hop.

Regenerating Satellite Mesh Architecture



ST-to-ST communications require one hop.
The Network Control Center (NCC) can be separated from the gateway.

The DVB-S/-RCS Standard

DVB-S defined in ETSI EN 300 421 has been conceived for primary and secondary distribution (Fixed Satellite Service, FSS) and Broadcast Satellite Service (BSS), operated in Ku and Ka bands.

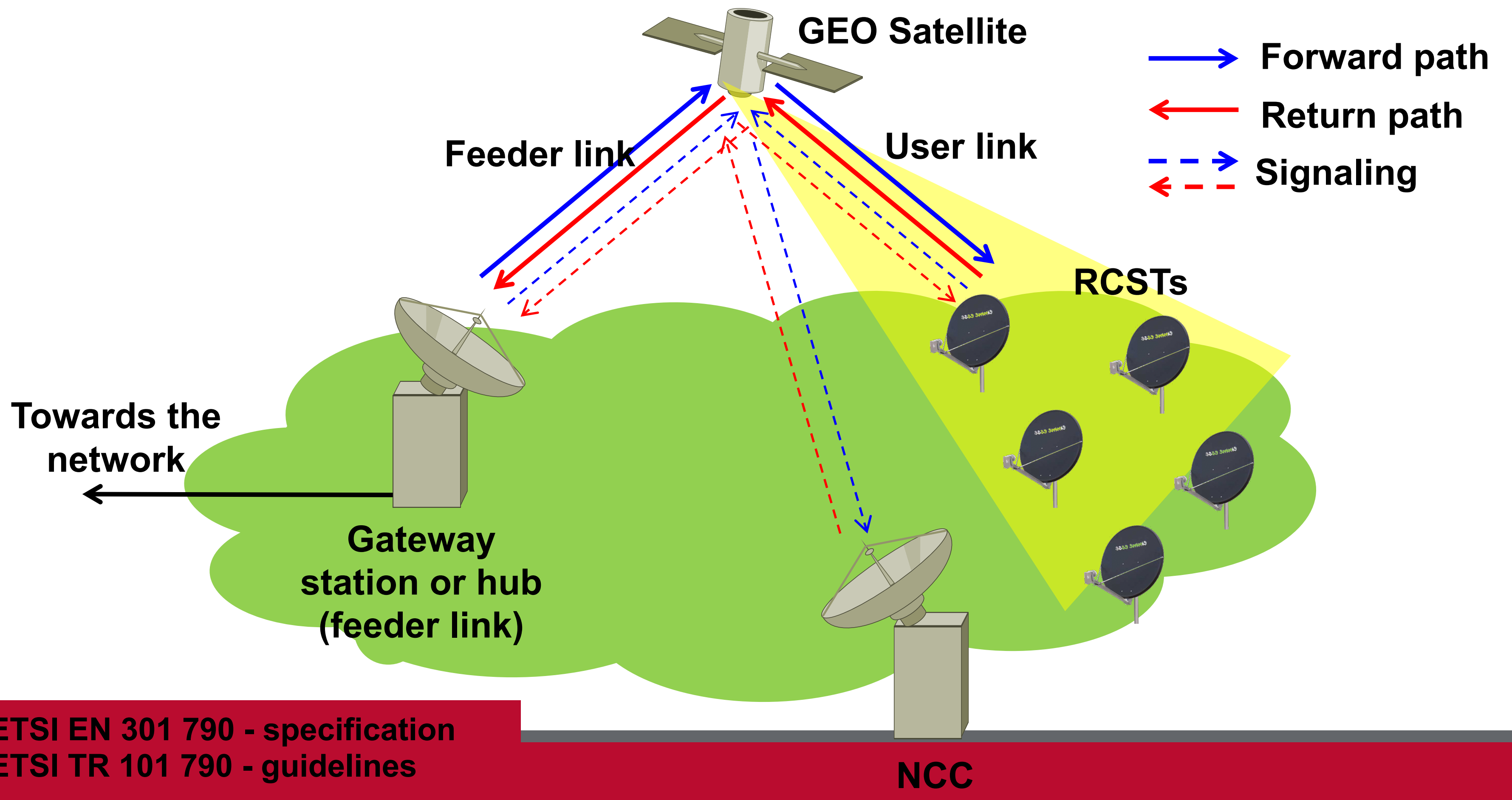
The DVB-RCS standard, specified in ETSI EN 301 790, defines a two-way DVB satellite system (i.e., both forward path and return one are considered) to support interactive services.

The network elements are:

- Return Channel Satellite Terminals (RCSTs);
- Earth station or gateway or hub for the interconnection with the terrestrial network;
- The Network Control Center (NCC) that operates acquisition/synchronization, Radio Resource Management (RRM), alarm management, security management, performance management, billing, and accounting.

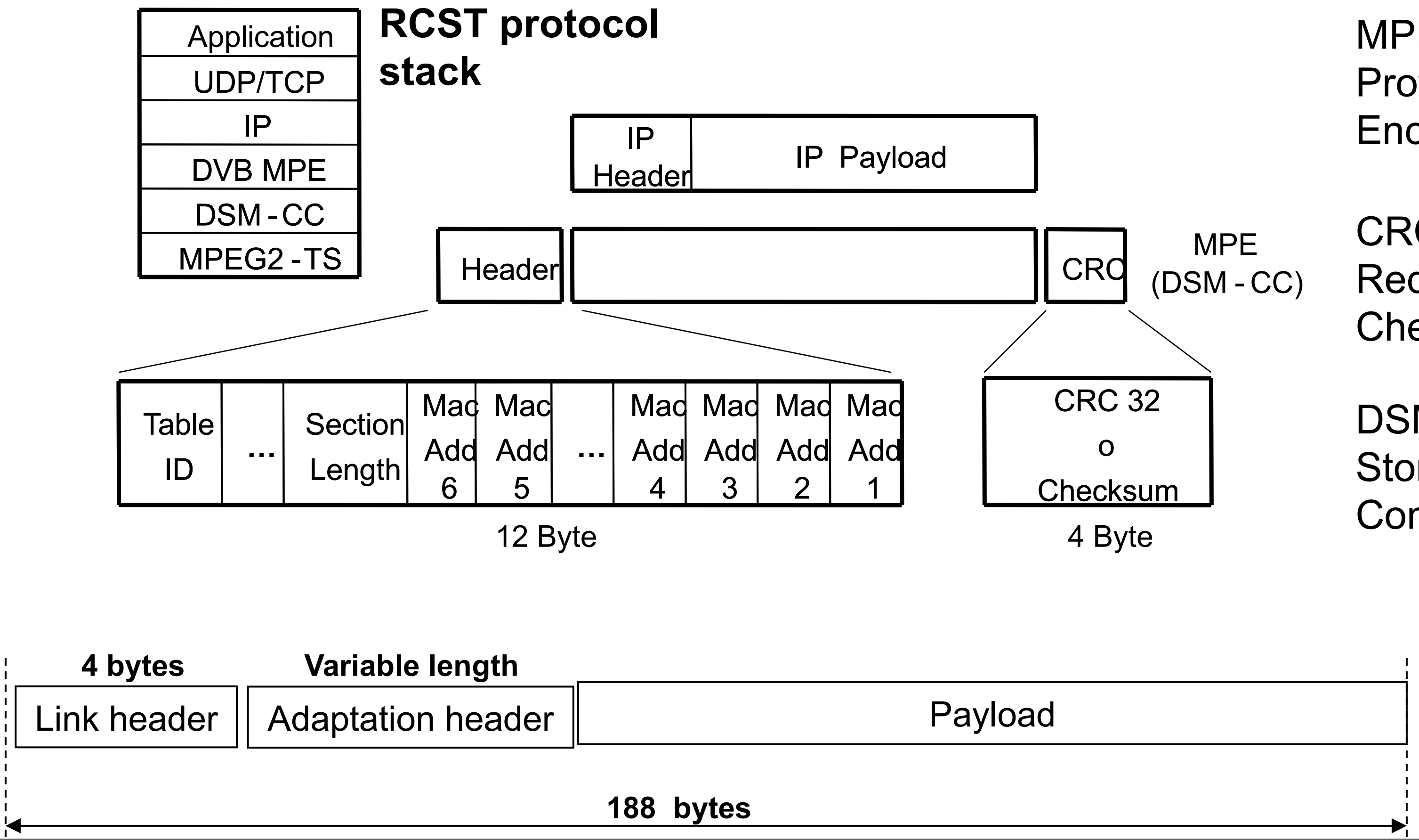
The DVB-RCS system envisages a Multi-Frequency Time-Division Multiple Access (MF-TDMA) transmission in the **return link** (from terminals to the hub) and uses the DVB-S standard (TDM transmission) for the **forward link** (from the hub to terminals).

DVB-S/-RCS Network Reference Scenario



ETSI EN 301 790 - specification
ETSI TR 101 790 - guidelines

DVB-RCS Air Interface Protocol Stack



MPE: Multi Protocol Encapsulation

CRC: Cyclic Redundancy Check

DSM-CC: Digital Storage Medium-Command & Control

MPEG2-TS packet structure

Traffic Classes in DVB-RCS

Traffic classes (called profile classes) in DVB-RCS are standardized as follows (similarly to ITU-T Y.1541 Recommendation):

1) Real-time priority traffic;

2) Variable-rate priority traffic, no jitter tolerant;

3) Variable-rate priority traffic, jitter tolerant;

4) Jitter-tolerant priority traffic;

5) Other priority traffic;

6) Best effort.

DVB-RCS Network Profile Classes

Profile Class	Delay	Jitter	PLR	Application example	Recommended capacity allocation method (**)
1	highly sensitive (hundreds ms)	highly sensitive (some tens ms)	loosely sensitive ($\leq 10^{-3}$)	Voice-based	**CRA**
2	sensitive ($\leq$ 1 s)	highly sensitive (some tens ms)	sensitive ($\leq 10^{-4}$)	Real time TV-cast, Interactive TV	**CRA**
3	sensitive ($\leq$ 2 s)	loosely or not sensitive	highly sensitive ($\leq 10^{-6}$)	Real Time Transaction Data	**CRA+RBDC+FCA**
4	loosely sensitive (few seconds)	not sensitive (no upper bound)	sensitive ($\leq 10^{-4}$)	Web Browsing, Interactive Games	**CRA+RBDC+FCA**
5	loosely sensitive (some seconds)	not sensitive (no upper bound)	highly sensitive ($\leq 10^{-6}$)	File transfer	**CRA+RBDC+ (A)VBDC+FCA**
6	not sensitive (no upper bound)	not sensitive (no upper bound)	not sensitive (no upper bound)	e-mail, Fax	**(A)VBDC+FCA**

(**) More details on the DVB-RCS allocation methods are described in the next slide.

DAMA for DVB-RCS

Demand Assignment Multiple Access (DAMA) allows the **dynamic allocation of capacity** by following the RCST needs.

- DAMA is defined as a set of MAC protocols and algorithms that allow an RCST to request resources, when the RCST has traffic to pass to the gateway.

In a DAMA scheme, when an RCST has data to transmit, it first explicitly requests the needed capacity to the NCC.

- NCC allocates return channel time slots based on RCST requests.
- NCC informs all RCSTs of the assigned slots using **Terminal Burst Time Plan (TBTP)** messages over the forward channel.
- Each RCST looks at the received TBTP and transmits data in the allocated time slots.

In DVB-RCS, DAMA schemes are of two types: RBDC and VBDC (AVBDC is a variant of VBDC), as explained in the next slides.

Resource Allocation Categories

Continuous Rate Assignment (CRA):

- CRA is a **rate capacity** that shall be provided in full for each RCST.
- ~~CRA is a **fixed and static allocation** of resources after an initial set-up phase between RCST and~~ NCC.

Rate-Based Dynamic Capacity (RBDC):

- RBDC is a **rate capacity** that is dynamically requested by the RCST.
- RBDC capacity shall be provided in response to explicit requests sent by the RCST to the NCC, such requests being **absolute** (i.e., corresponding to the full rate currently being requested).

Volume-Based Dynamic Capacity (VBDC):

- VBDC is a **volume capacity** that is dynamically requested by the RCST.
- VBDC capacity shall be provided in response to explicit requests sent by the RCST to the NCC, such requests being **cumulative** (i.e., each request shall add to all previous requests from the same RCST: the request indicates the new packets arrived since the last request).

Free Capacity Assignment (FCA):

- FCA is a **volume capacity** that shall be assigned to RCSTs from capacity, which would be otherwise unused. Such capacity **assignment shall be automatic** and shall not involve any request made by the RCST

DVB-S2 Air Interface

DVB-S2 is a standard for satellite communications, developed to improve the performance of DVB-S.

3 modes of operation: **CCM** (Constant Coding and Modulation), **VCM** (Variable Coding and Modulation), and **ACM** (Adaptive Coding and Modulation)

For interactive traffic the sender site dynamically acquires information on the receiver channel conditions by means of a return link. **DVB-S2 uses ACM mode for interactive services.** ACM permits to change dynamically Modulation and Coding (ModCod) on the basis of the channel conditions reported.

DVB-S2 Spectral Efficiency

New Forward Error Correction (FEC) codes that are more powerful:

- BCH (Bose-Chaudhuri-Hocquenghem) replaces Reed Solomon outer coding
- LDPC (Low Density Parity Check) replaces Viterbi inner coding

Inner code-rates:

- 1/4, 1/3, 2/5, 1/2, 3/5, 2/3, 3/4, 4/5, 5/6, 8/9, 9/10

New modulation schemes

- QPSK, 8PSK, 16APSK, 32APSK

3 spectrum shaping (roll-off) factors:

- 0.2, 0.25, 0.35 %

Available DVB-S2 ModCods

ModCod ID	Bit rate in Mbit/s (25 MHz)	Standard E_b/N_0 thresholds in dB
#1	12.25	0.75
#2	16.41	0.59
#3	19.73	0.73
#4	24.72	1.05
#5	29.70	1.48
#6	33.05	1.88
#7	37.18	2.30
#8	39.68	2.67
#9	41.36	2.99 (Not used)
#10	44.16	3.73 (Not used)
#11	44.71	3.89
#12	44.49	2.99
#13	49.51	3.65
#14	55.70	4.43

ModCod ID	Bit rate in Mbit/s (25 MHz)	Standard E_b/N_0 thresholds in dB
#15	61.96	5.41 (Not used)
#16	66.15	6.46 (Not used)
#17	66.98	6.70 (Not used)
#18	65.93	4.76
#19	74.16	5.49
#20	**79.14**	**6.03**
#21	82.50	6.43
#22	88.07	7.42 (Not used)
#23	89.18	7.60 (Not used)
#24	92.58	7.04
#25	98.78	7.67
#26	102.98	8.13
#27	109.94	9.26
#28	111.32	9.56

ModCod selection for fixed users based on a Packet Error Rate (PER) requirement: PER $\leq 10^{-7}$ (Quasi Error Free -QEF- criterion). The E_b/N_0 thresholds in the above tables are for AWGN channel.

Encapsulation Methods for IP Packets in DVB-S2/-RCS

Multi Protocol Encapsulation (MPE): MPE encapsulation over MPEG2-TS format over BBframe.

Generic Stream Encapsulation (GSE): GSE encapsulation directly over BBframe. This encapsulation allows a **better efficiency** (lower overhead).

DiffServ Adoption

DVB-RCS supports QoS **differentiation by means of the DiffServ (DS) approach (this is also true for DVB-RCS2)**.

RCST can be an interior node in a DS domain or an edge node of the DS domain.

RCSTs have to support the following PHBs:

- Expedited Forwarding PHB
- At least one Assured Forwarding PHB Class (AF3) with at least two drop precedence levels
- Best Effort PHB.

As a DS node, the RCST is capable of mapping packets to the different PHBs supported by the DVB-RCS network.

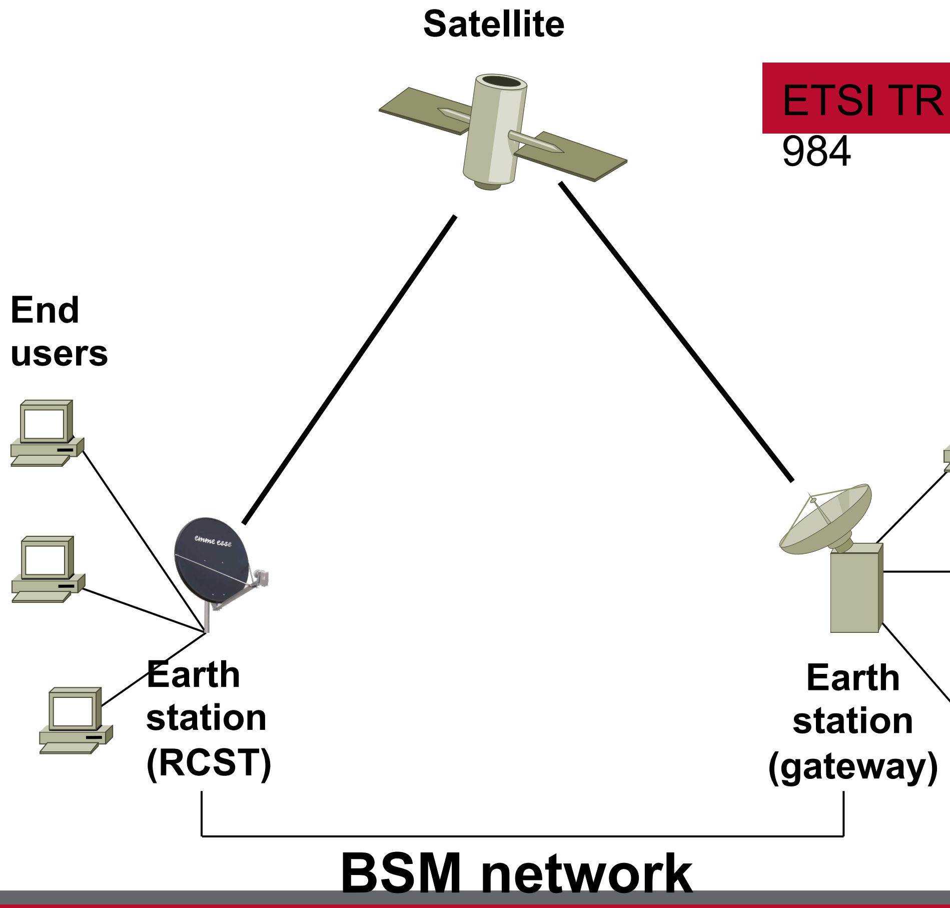
DVB-RCS Requirements for RCST

PHB	Delay	Jitter	Priority	Bandwidth	Packet loss rate
EF	< 300 ms	< 50-100 ms	Very high	Full, at session set up	< 0.1%
AF31/AF32	< 850 ms	–	High	–	< 0.1%
BE	< 850 ms	–	Low	–	–

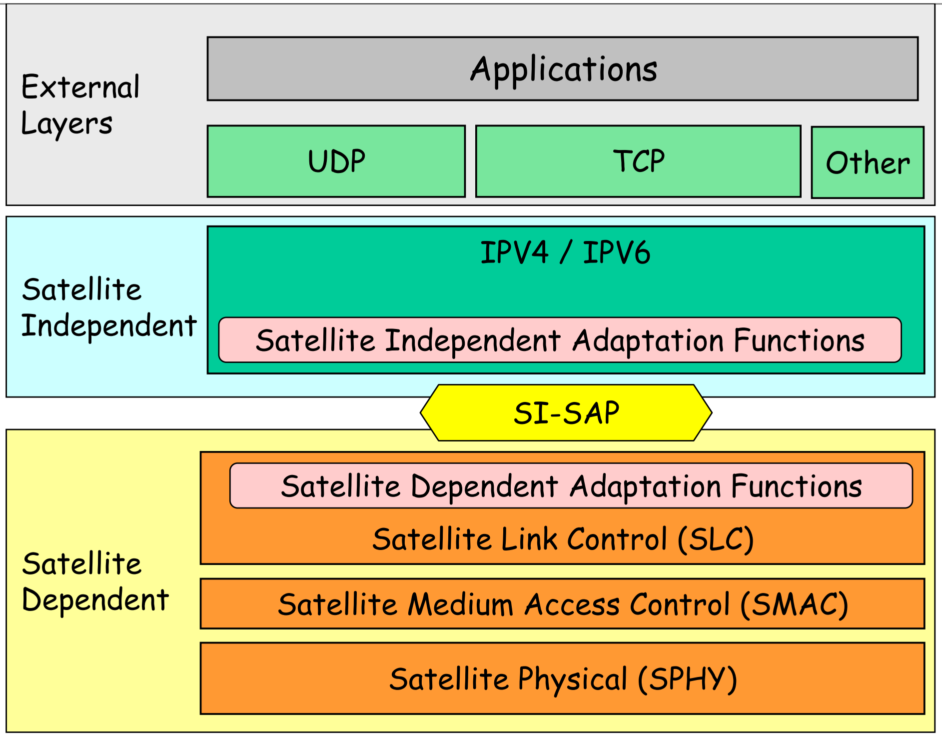
The ETSI Standard for Broadband Satellite Multimedia (BSM) Networks

- An earth station has the function of a **gateway** towards the Internet.
- If the satellite is bent-pipe, an earth station is used as a **hub** to allow the interconnection of **terminals** [known as a Satellite interactive Terminals (STs) or Return Channel Satellite Terminals (RCSTs)].
- An RCST can even represent the aggregation point of multiple users (collective terminal).

ETSI TR 101 984



BSM Reference Protocol Stack: SI-SAP Interface



ETSI TS 102 465

This is the protocol stack architecture proposed by the ETSI BSM group, related to RCSTs and to gateways.

We note two parts connected by SI-SAP (Satellite Independent-Service Access Point): **Satellite-Independent (SI) protocols** that are typical of the Internet protocol layers and **Satellite Dependent (SD) layers** that depend on the satellite system implementation.

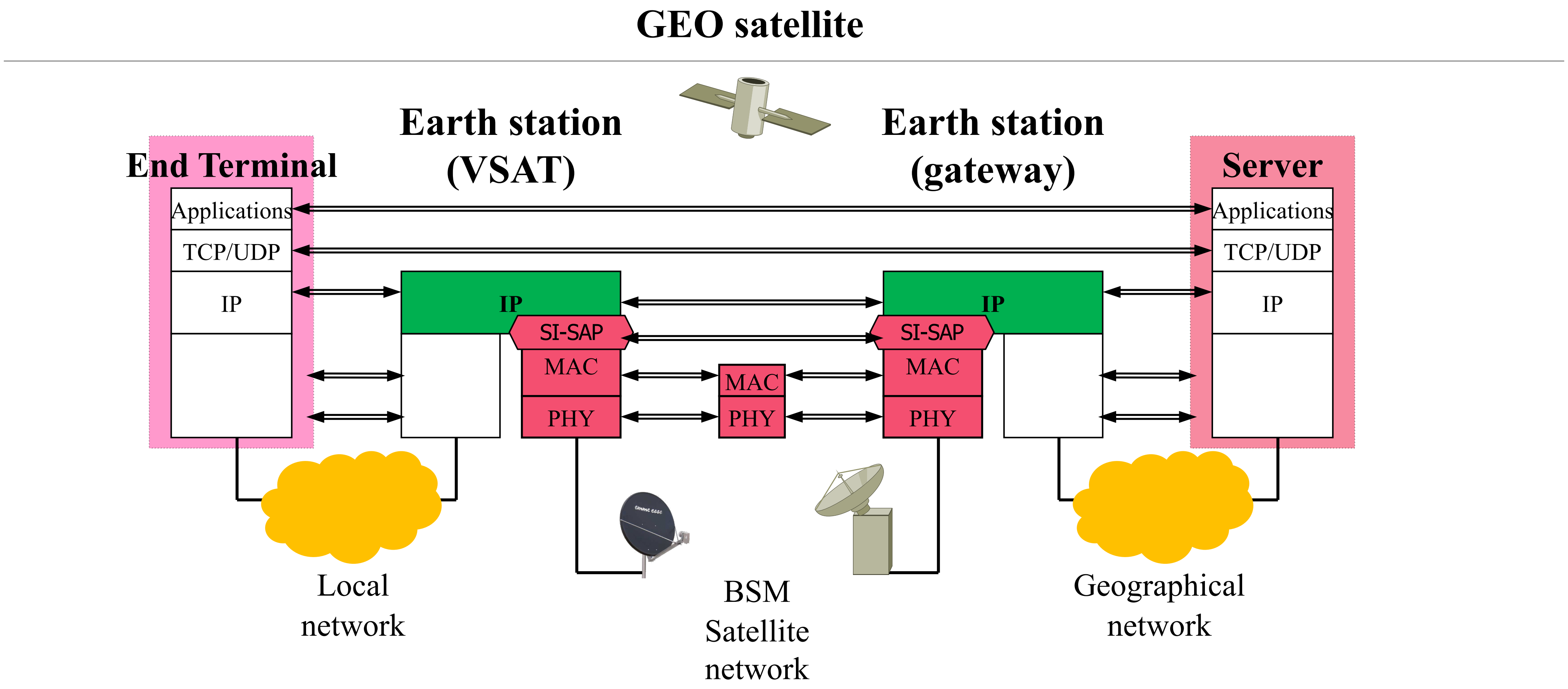
SI-SAP primitives are used to exchange data and signaling among SI and SD layer protocols.

The ETSI BSM Standard

A BSM network can interconnect with external IP networks at different layers of the protocol stack (ETSI TR 101 985) according to the cases listed below:

- The BSM network interconnects with ground network elements at layer 2, like a **bridge**.
- The BSM network interconnects with ground network elements at layer 3, so that the satellite earth stations are **routers**.
- The BSM network operates at a layer above the 3rd one: the satellite earth stations are **gateways**.
  - In such a case, the earth station can implement special functions, like **Performance Enhancing Proxies (PEP)** that are important to improve the performance of the TCP protocol in satellite networks (LFNs).

Architecture of a Layer 3 BSM Network



BSM Traffic Classes

BSM networks use a specific categorization of traffic flows in traffic classes.

The BSM traffic classes are defined at the SI-SAP interface and refer to the IP packets (and their class of service) which are arriving at this interface.

There are **8 BSM traffic classes, i.e., service priority levels, from 0 for emergency services to 7 for low priority broadcast/multicast traffic**.

The **8 BSM traffic classes represent an adaptation of the ITU-T Recommendation Y.1541 classes** at SI-SAP level.

ETSI, "Satellite Earth Stations and Systems (SES). Broadband Satellite Multimedia. Services and Architectures; BSM Traffic Classes", *ETSI Technical Specification*, TS 102 295 V1.1.1, February 2004.

BSM Traffic Classes and Queue Issues at Layer 3

priority

BSM traffic class	Service category	Node mechanism	DiffServ, Mapping on PHBs
0	Emergency services, essential network services	Pre-empts any traffic that has allocated bandwidth	**EF**
1	Real-time, jitter-sensitive , high interactive fixed size cells VoIP	Separate queue with preferential servicing, traffic grooming, strictly admitted	**EF**
2	Real-time, jitter sensitive, interactive, variable rate cells	Separate queue with preferential servicing, traffic grooming, loosely admitted	**EF**
3	Highly interactive (signaling), transaction data	Separate queue, drop priority, strictly admitted	**AF**
4	Interactive, transaction data	Separate queue, drop priority, flow controlled	**AF**
5	Low loss only	Long queue, drop priority, flow controlled	**AF**
6	Medium loss, higher delay (traditional applications of IP networks)	Separate queue, flow controlled	**BE**
7	Not specified, low priority broadcast/multicast traffic or storage networks (with reliable higher layer	Separate queue	**BE**

SI-SAP Role for QoS Support

According to satellite industry view and standardization, **it is accepted that at the IP level (above SI-SAP) between 4 and 16 queues are manageable to support different IP classes. While, below SI-SAP these queues can be mapped into 2-4 satellite-dependent queues within the BSM, depending on the different capacity allocation schemes supported by the satellite system.**

This structure requires that SI-SAP performs a **vertical QoS mapping between SI layer queues and SD ones**.

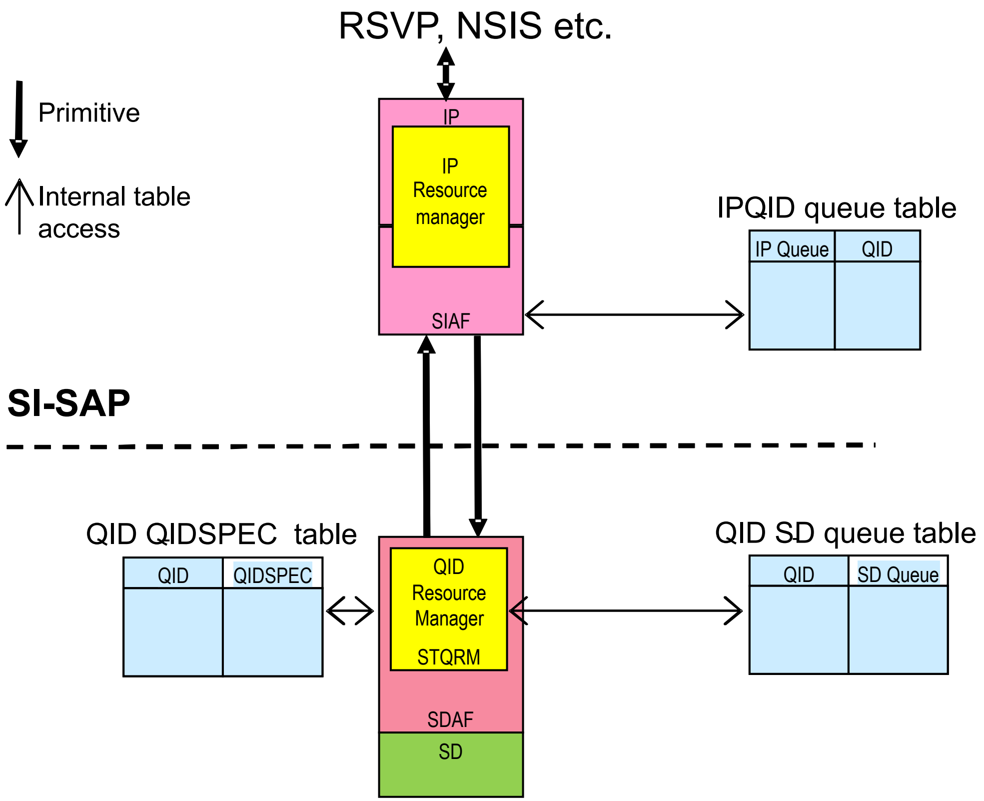
All BSM services are based on **SI-SAP primitives**; these primitives are used to manage the exchange of information between SI upper layers and SD lower layers via SI-SAP.

SI-SAP QoS Vertical Mapping

SI-SAP supports a QoS interface based on the concept of QIDs (Queue Identifiers) that are specified **to support both IntServ and DiffServ**.

- **QIDs are abstract queues** that represent layer 2 queues in a general way to allow the mapping with layer 3 ones (IntServ or DiffServ).
- Each QID queue is characterized by **QoS-specific (QIDSPEC) parameters** (flowspecs, path label, marking) and is associated to lower layer capacity allocation methods, including buffer management and policing. **The SD layers are responsible for assigning satellite capacity to these abstract queues.**
- The mapping of IP queues to QIDs can be flexible (not necessarily a one-to-one relation).
  - If more IP queues correspond to the same QID, a scheduler should be used at layer 3 to determine the service order of the different IP queues that correspond to the same QID queue.

QID QoS Specifications



QID QoS Specification (QIDSPEC) based on a token bucket model

- Token Bucket Rate [r]
- Token Bucket Size [b]
- Peak Data Rate [p]
- Minimum Policed Unit [m]
- Maximum Packet Size [M]
- Rate [R]
- Slack Term [S]

Interworking with DiffServ QoS

As for DiffServ, let us recall what follows:

DiffServ aggregates IP flows by means of packet marking using the DSCP field of the IP header.

DiffServ provides QoS support per traffic aggregates.

DSCPs are determined by pre-defined policies and SLAs, or optionally set dynamically by means of signaling protocols.

Traffic flows marked with the same DSCP constitute a Behavior Aggregate (BA) and receive the same level of service from a DiffServ node, i.e., the same Per-Hop Behavior (PHB).

BSM issues:

Packets receive a given QoS treatment from one particular satellite terminal when they are forwarded over the satellite.

DSCPs need to be carefully mapped to SD classes of service in the satellite terminal.

SD classes are system-dependent.

TCP over Noisy Links with Long Propagation Delays

The slow start phase of TCP takes a long time to fill the pipe (whose capacity is expressed by BDP):

- $\propto \log_2(\mathrm{BDP})$ in RTTs units

After an RTO expiration, TCP enters the slow start phase so that a lot of time is needed to recover the goodput.

- TCP has a poor performance (efficiency) in high-capacity links with high packet loss rates, like in satellite networks.

TCP infers congestion from packet losses:

- Even if the packet loss is due to channel effects, TCP reduces unnecessarily the traffic injection.

PEP Issues (ETSI TR 102 676)

Performance Enhancing Proxies (PEPs) are adopted in the network and operate at different levels. We consider below two typical cases relevant to the satellite scenario.

- **PEPs at transport layer** are used to generate/manage local ACKs in order to improve the TCP goodput. For instance, the **TCP split technique** foresees to intercept a given TCP flow and terminates it by providing back ACKs, thus reducing the RTT seen by the TCP source.

- **PEPs at the application layer** are used as local **caches** in the Internet.

PEP Implementing TCP Splitting

The aim of a PEP at transport layer is to separate the satellite segment from the rest of the network: the end-to-end TCP connection is split into two or three connections (**integrated PEP** or **distributed PEP**, respectively):

- First TCP connection: from the satellite sender to the PEP; Low RTT, error free; use of standard TCP.
- Second (and third) TCP connection(s): from the PEP to the satellite receiver or to another PEP; Long RTT, possible PER; use of an optimized TCP version.

Advantages:

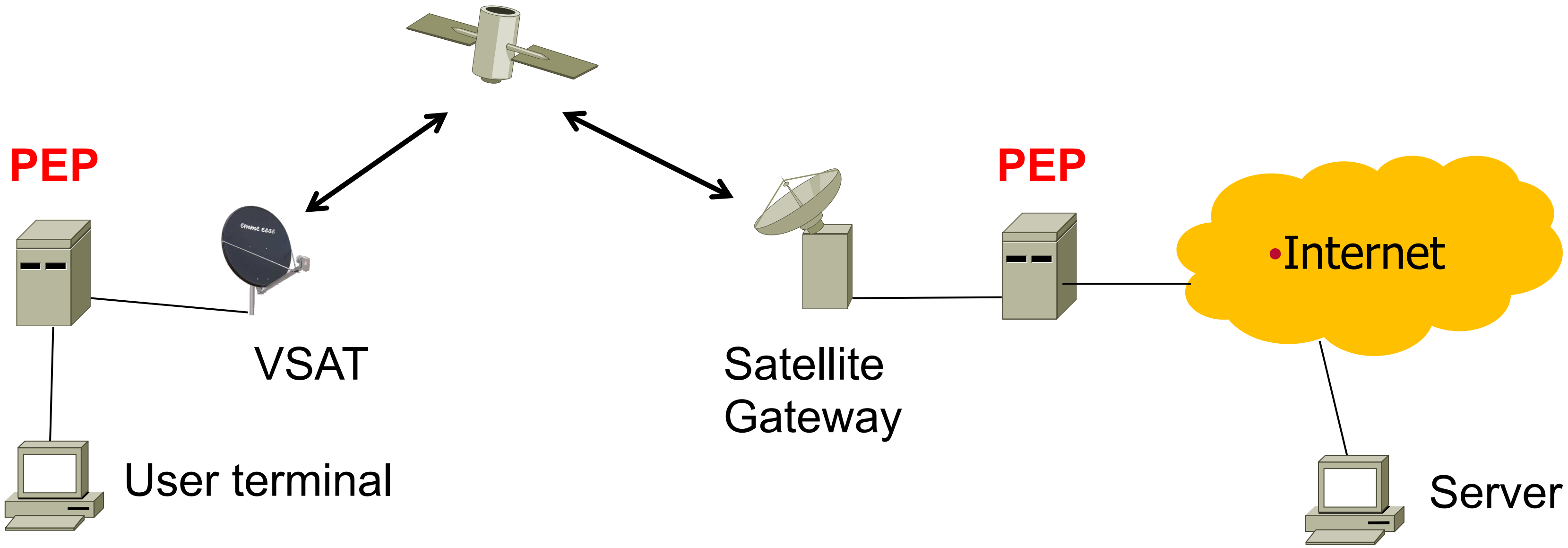
- Very good performance
  - RTT unfairness (heterogeneous environment) solved by the splitting approach;
  - Satellite impairments tackled by an optimized TCP version.

Disadvantages:

- Violation of end-to-end TCP semantics and incompatibility with IPsec.

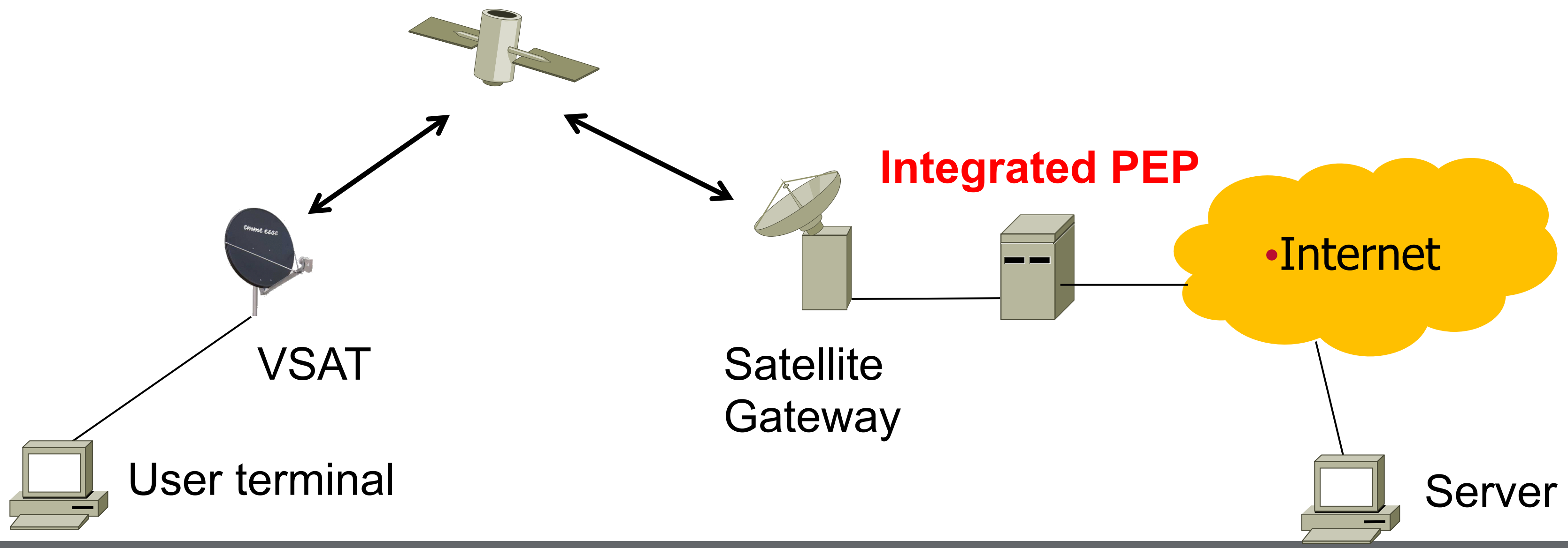
Architecture with Distributed (two) PEPs

The TCP end-to-end path is split into three parts: two PEPs isolate the satellite links where an accelerated (optimized) TCP version can be used.



Architecture with Integrated (Single) PEP

The TCP end-to-end path is split into two separated connections, with the integrated PEP at the Gateway. The connection between server and integrated PEP uses standard TCP. The connection between PEP and final user can use an enhanced TCP version compatible with a standard TCP receiver.



The Future of Satellite Communication Systems

New demands concerning TV [HDTV/3DTV (**large bandwidth**) and IPTV (**large traffic**)] are rapidly spreading the market.

Space-segment requirements: high throughput, flexibility, and reconfigurability.

Next-generation wideband **Ka-band payloads** (Gigabit/s) with **multi-spot beam antennas**.

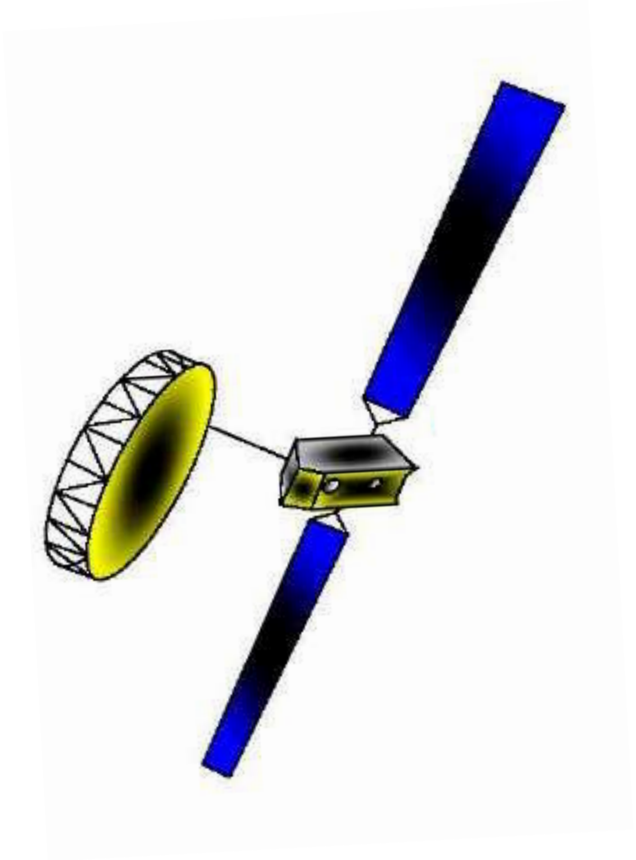
Regenerating payloads: optical interconnection, optical switching, inter-satellite links.

Mobility support: use of **hybrid/integrated systems** with a terrestrial ancillary wireless component.

Details on Recent GEO Satellite Systems

Satellite type	Band (user link)	Number of transponders	Number of beams
Inmarsat-4 (BGAN)	L	50-90 (C and L band)	256
HotBird 9, 13C	Ku	64	1
Amazonas 2	Ku and C	54(Ku)+10(C)	3
Intelsat 23	Ku and C	15(Ku)+24(C)	5
Inmarsat 5 (Global X-press)	Ka	89+6	89+6
HYLAS 1	Ka	8(Ka)+2(Ku)	8
KaSAT	Ka	57(Ka)	82

Inmarsat-4 Satellites (BGAN System)



Spacecraft DC power: 12 kW

L-band EIRP (narrow spots): 67 dBW

Beams : 200 narrow spots, 19 wide spots, 1 global beam

G/T (narrow spots) : > 10 dB/K

Launch mass : 6 Tons

Solar array span : 45 m

Reflector size : 9 m

Voice circuits : 16000 at 4.8 kbit/s

Broadband data : 500 at 400 kbit/s

Prime contractor : Astrium

Launchers : Atlas 5 (ILS) and Zenith, 3SL (sea launch)

Some Satellite Systems for Mobile Communications

System	Orbit type, altitude [km], satellite name	Services	Access scheme	Frequency bands
GlobalStar	48 LEO, 1414	Mobile satellite system voice and data services	Combined FDMA & CDMA (uplink and downlink).	Uplink: 1610.0 - 1626.5 MHz (L-band) Downlink: 2483.5 - 2500.0 MHz (S-band)
Iridium	66 LEO, 780	Mobile satellite system voice and data services	FDMA/TDMA - TDD for both uplink and downlink	Uplink: 1616-1626.5 MHz (L-Band) Downlink: 1610-1626.5 MHz (L-Band)
ICO (new ICO)	12 MEO (10 active), 10355 (changed to 10390 km, late 1998)	ICO is planning a family of quality voice, wireless Internet and other packet-data services.	FDMA/TDMA - FDD	Uplink: 1980 - 2010 MHz Downlink: 2170 - 2200 MHz C/S bands
Spaceway	16 GEO + 20 MEO, 36000 – 10352	With Spaceway, large businesses, telecommuters, *Small Office - Home Office* (SOHO) users and consumers will have access to two-way, high-data-rate applications such as desktop videoconferencing, interactive distance learning and Internet services.	Uplink: FDMA/TDMA Downlink: TDMA	Uplink: 27.5 - 30 GHz Downlink: 17.7 - 20.2 GHz Ka band
Thuraya	2 GEO	Voice telephony, fax, data, short messaging, location determination, emergency services, high power alerting	FDMA	Uplink: 1626.5-1660.5 MHz Downlink: 1525-1559 MHz L/C bands
Eutelsat (operator)	GEO satellites (e.g., Hotbird 4, Hotbird 6) equipped with the Skyplex regenerating transponder	Single digital TV programme broadcasting, digital radio broadcasting, interactive multimedia services and Internet connectivity	Uplink: DVB-RCS (TDMA) Downlink: DVB-S	Uplink: 13.75, 14- 14.50, 29.50-30 GHz Downlink: 10.70, 10.86- 12.75, 19.70-20.20 GHz Ku and Ka band
Wildblue	GEO (Anik F2)	High-speed broadband Internet access, satellite television, distance learning and telemedicine	Uplink: TDMA Downlink: MF-TDMA	Uplink: 5.9 - 6.4 (C band), 14 - 14.5 (Ku band), 28.35 - 28.6 and 29.25 - 30 GHz (Ka band) Downlink: 3.7 - 4.2 (C band), 11.7 - 12.2 (Ku band), 18.3 - 18.8 and 19.7 - 20.2 GHz (Ka band)
IPStar	GEO	Broadband access, Intranet and VPN, Broadcast/Multicast, Video on Demand, Voice, Leased Circuit/Trunking, Video Conferencing	Uplink: MF-TDMA Downlink: TDM/OFDM	Uplink: 13.775-13.975, 14 - 14.5 GHz Downlink: 10.95 – 11.2, 11.5 - 11.7, 12.2 – 12.75 GHz
Inmarsat	11 GEO (10 active sats.): 4 Inmarsat-2, 5 Inmarsat-3, 2 Inmarsat-4	Simultaneous voice&data, Internet&Intranet content and solutions, Video-on-demand, videoconferencing, fax, e-mail, phone and LAN access	TDMA	Uplink: 1.626 - 1.66, 1.98 - 2.025 GHz Downlink: 1.525 - 1.559, 2.16 - 2.22 GHz